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Fuel Consumption of Rotary Cement Kilns.

THE earliest Portland cement kilns were of the bottle and shaft types, both of small capacity and worked intermittently. Neither kiln had facilities for drying the slurry and this had to be carried out as a separate process. The weight of fuel used for burning alone was possibly up to 40 per cent. of the clinker produced, but no figure can be stated for the fuel used for drying the slurry. Gas-works coke was used for burning and coke breeze for drying.

These kilns were gradually superseded by kilns of the tunnel and chamber types, both of much larger capacity but still of the intermittent type. These kilns were constructed with a chamber for drying the slurry and were thus independent of the separate dryer. The drying chambers in some cases were large enough to dry a small amount of slurry in excess of their own requirements, and this could be used in bottle and shaft kilns. The weight of fuel used in the tunnel and chamber kilns was about 40 per cent. to 45 per cent. that of the clinker produced. Gas-works coke was used in both these kilns.

Vertical shaft (Schneider) kilns, with and without forced draught, and arranged for continuous operation, were used later in connection with dry-process installations ; these kilns had a fuel ratio of 18 per cent. to 24 per cent., but the clinker produced was not always well burnt and selection proved necessary when cement of good quality was required. Coke, coke and coke breeze, and " rubbly culm " were used as fuel at different times and under different conditions in these kilns.

Annual Consumption of Coal.

When rotary kilns were first used the weight of fuel required was about or fully 40 per cent. of the weight of clinker produced, and washed slack or equal was used as fuel. This proportion has been gradually reduced until at the present time the mean for the whole of the kilns in commission in Great Britain may be

27 per cent. For a few selected kilns it may be as low as 22 per cent. to 23 per cent.; these kilns, however, would be those with modernised equipment and auxiliaries which have contributed to economical working. It is not practicable to apply such improvements to all existing kilns and, moreover, the saving in fuel would not justify the cost involved.

The difference in fuel consumption between 27 per cent. and 22 per cent. for a works producing 4,000 tons of cement a week (say, 200,000 tons a year) is 10,000 tons of coal a year, which with coal costing, say, 30*s.* a ton, would amount to £15,000 a year in addition to the cost of handling and pulverisation, which might easily cost up to 1*s.* a ton or, say, £500 a year. It is realised that some cost would be involved in making this saving, but even so there would still be a substantial margin. The annual saving based on a total cement output of 8,750,000 tons (one of the figures referred to in the report recently made by the committee on cement production appointed by the Ministry of Works and Buildings) would amount to 437,000 tons of coal, and the value would be, say, £676,000.

Shaft Versus Rotary Kilns.

In comparing the operation of the shaft kiln with a fuel consumption of 18 per cent. to 24 per cent. of the clinker produced and the rotary kiln with a consumption of 22 per cent. to 27 per cent., it has to be remembered that the shaft kiln was fed with fuel, with air for combustion, and with pressed briquettes of raw material—slightly moistened—at atmospheric temperature. The clinker was discharged at 200 deg. F., the gases were emitted at about the same temperature, and the whole of the heat for drying and heating, as well as that used in the de-carbonating and calcining processes, which should reach a peak of 2,500 deg. F., was provided for. The pressed briquettes provided for the shaft kiln call for an additional operation, but a compact plan and a good arrangement of machinery should reduce the inconvenience and extra cost to a minimum. It is admitted that the shaft kiln does not lend itself to construction in large units so well as does the rotary kiln; in any case, this has not as yet been tried out. We are, however, especially concerned with fuel, and must not allow other factors to enter too fully into the consideration.

The rotary kiln receives its fuel and primary air for combustion at a temperature of not less than 150 deg. F.—the latter might be very much higher. The clinker is discharged at 150 deg. F. to 450 deg. F. The gases are emitted at a temperature of between 450 deg. F. and 650 deg. F., or sometimes even higher. The maximum temperature in the process is probably rather higher and much more consistent than that of the shaft kiln.

From the foregoing it would appear that the principal operating difference between the two types of kiln is the temperature of the effluents, but in either case all usable heat in the clinker or gases should be regarded as waste and every effort made to reclaim this heat if at all practicable. The ideal would be to use in any cycle all the heat that is released during that cycle.

Methods of Reducing Fuel Consumption.

Various attempts have been made, with varying degrees of success, to reduce fuel consumption. The most noticeable and possibly the most successful amongst these are (1) various arrangements of chains ; (2) the recuperator kiln (or cooler) ; (3) the Lepol kiln (or grate) ; (4) the calcinator (kiln) ; and (5) the clinker grate-cooler. The following other methods may also be mentioned as having at some time been tried, but none of them—except the slurry filters—has been very successful ; in fact, most of them are now only a memory.

Slurry Lifters.—Lifters took and still take many forms. Lengths of angle and channel section fixed to the shell can operate as lifters, as also can circular and hexagonal tubes of large size fixed within and across the shell and extended for some distance down it. The surfaces of these lifters are, or should be, immersed

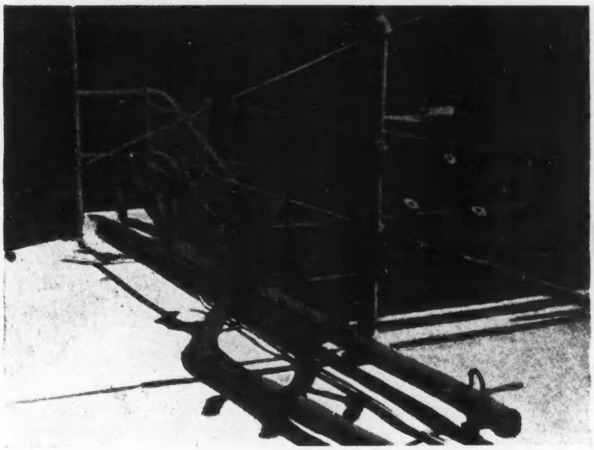

Fig. 1.—Assembly of 4-Nozzle Spray Group.

in the slurry and cooled every part-revolution of the kiln, and then dried and heated during the other part of the revolution, the object being a large surface for coating and drying for heat transfer. Lifters have proved very satisfactory for dry materials, i.e. clinker, coal, limestone, shale, etc., but not for slurry. The use of lifters for slurry was continued for a long time, but no figures can be cited showing any definite saving made by them. It is possible that efficiency figures were not examined so critically when lifters were in more general use as they are now. Lifters rarely, if ever, behave satisfactorily when used with slurry made from marl or any glutinous material ; their operation would possibly be free from trouble if they were used with a chalk or limestone slurry.

Slurry Sprays.—A complete group of four spray nozzles is shown in *Fig.* 1. This group can be positioned and removed as a unit and the back end-chamber

must be arranged with that object in view. The arrangement indicated makes no provision for supplying the kiln during the time the spray group is removed for repair or replacement. Slurry sprays were very useful in obtaining reduced fuel consumption and lower back-end temperature, and they also increased the rated capacity of the kiln. Some of the mechanical details proved very troublesome and called for much maintenance with resultant loss of output. The loss of material as dust was also very serious, and the dust resulting from the use of sprays rendered the system prohibitive in residential areas. Many attempts were made to cure the trouble but without complete success, and ultimately sprays were discarded. Sprays appear to be suitable for use in non-residential areas only or on carefully-selected sites, but some arrangement for collecting the dust is necessary.

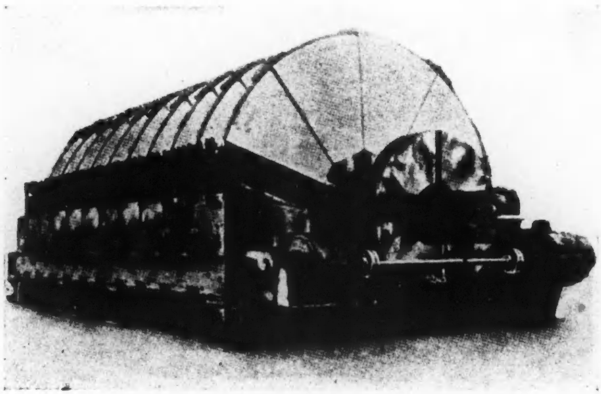

Fig. 2.—Assembly of Disc-Type Filter.

Slurry Filters.—Slurry filters are used with a fair amount of success in the United States where the raw materials appear to be generally more suitable for the use of these machines. There are two principal types of slurry filter, namely the disc and drum types, the principle of operation of which is the same. It is possible, however, to obtain the greatest filtration area in the same floor space with the disc type, which is shown in profile in *Fig.* 2.

A recent article in *Rock Products* stated that as far back as 1934 no fewer than thirty-four kilns in the United States were equipped with filters and that the raw materials used in the respective slurries were limestone and slag (shale ?), limestone and clay, and chalk and clay. It was also stated that the use of filters enabled the moisture in these slurries to be reduced from 34 per cent., 38 per cent. and 48 per cent. respectively to lower figures that result in an average of 23 per cent.; if this average were as high as 25 per cent. it would represent a considerable reduction on British practice, which ranges between, say, 35 per cent. and 42 per cent. The use of filters enables high moisture to be retained all

through the processes—which is a decided advantage—and then reduced immediately before the slurry is passed into the kiln. The use of filters involves the use of a number of auxiliaries and some additional labour ; it may be assumed, however, that the practice is worth while, otherwise it would not have been continued in the United States. It has been stated elsewhere that a difference of 1 per cent. of moisture in the slurry is equivalent to a difference of 0·8 per cent. in fuel consumption.

Chain Systems.—Chain systems in some form or other, with or without conveyor spirals, are almost universally in use and have proved of real value in the reduction of fuel. Chains will work under most but not all conditions. Their success depends primarily upon whether the system adopted is suitable for the raw material, for an arrangement of chain that suits one class of material will not necessarily work with another material. The number of different types of chain systems is legion and no useful purpose would be served by showing more diagrams. The underlying principle is to ensure that the chains are immersed and cooled in the slurry, and withdrawn and dried and heated by the gases, alternately ; the movement of the chains should also control the movement of the slurry as it passes down the kiln.

When the material is of a gritty or crystalline structure a suitable chain system will work without trouble and full advantage will be obtainable by its use. Where the material is of a glutinous nature chains have only a remote chance of success or, alternatively, only a limited system will work and full advantage cannot be obtained. Under the best conditions, and if the arrangement of chains and the characteristics of the raw material are suited to each other, a fuel reduction of from 29 per cent. or 28 per cent. without chains to 24 per cent. with chains may be obtained. In no case, however, does it appear possible for the fuel to be reduced below 24 per cent. or 23 per cent. by a chain system alone. Either of these figures will probably call for a very low rating for the kiln, and possibly for some special feature in the proportions of the kiln. Any efficient chain system will call for a constant moisture in the slurry and close regulation of the kiln to ensure that the conditions within the chain system are consistent and always the same.

The Recuperator Kiln (Cooler).—*Fig.* 3 shows a kiln with a multi-cylinder cooler attached. The clinker on leaving the kiln enters one end of a cooler cylinder, is conveyed to the other end of the cylinder as the result of the internal fittings and the rotation of the kiln, and is discharged. The general design involves a heavy overhang of the lower end of the kiln. This arrangement enables the detached cooler to be discarded. Cooling is effected during the passage of the clinker through the small cylinders, and the secondary air for combustion is heated as part of the operation. The clinker passes outwards, the air flows inwards, and heat exchange takes place, and if the parts are of correct proportions the temperature of the clinker will be reduced considerably and the temperature of the air will be raised relatively high. An equipment of lifters and chains is invariably fitted inside the cylinders to intensify the heat exchange.

The principal claim for the recuperator kiln is that the heat loss is, or should be, less than that of the detached cooler owing to the multi-cylinder cooler being part of, or not separated from, the kiln ; that is, the construction is proof against leakage of air at this point. On the other hand it is really difficult, in the small cylinders, to obtain all the facilities for clinker cooling and air heating that is possible with the detached cooler, which is of considerably larger dimensions.

The recuperator type kiln with multi-cylinder cooler has not proved fool-proof ; in any case, the fuel consumption of this type of kiln-with-cooler has not been any lower than that of a kiln having a detached cooler of good proportions. The temperature of the clinker as usually discharged from the multi-cylinder coolers is invariably 150 deg. F. to 200 deg. F. higher than that of the detached coolers. The internal volume of a well-proportioned detached cooler is 20 per

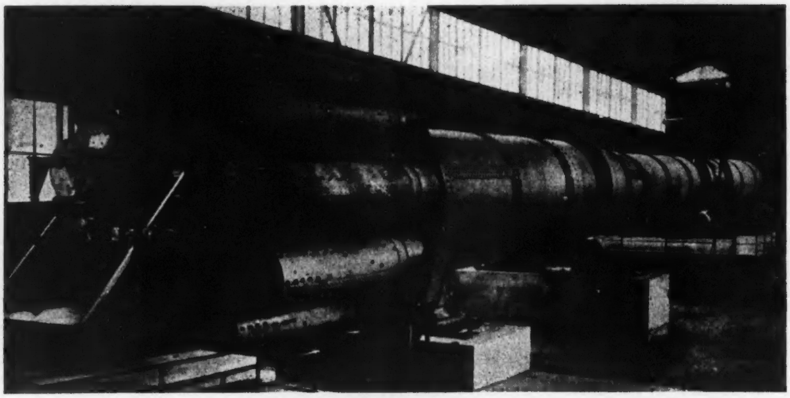

Fig. 3.—Recuperator-Type Kiln.

cent. to 25 per cent. of that of the kiln, whereas the cumulative internal volume of a multi-cylinder cooler is usually less than 10 per cent. of that of the kiln. This small capacity probably accounts for the limited amount of cooling that is invariably effected, and it is possible that the temperature rise of the combustion air is limited in the same way, though no figures appear to be available.

The Lepol Kiln and Grate.—This auxiliary is especially suitable for use in dry process installations and comprises (*a*) a nodule-producing machine, (*b*) a travelling chain grate, and (*c*) a high-duty exhaust fan ; special conditions also apply to the firing end of the kiln. *Fig.* 4 shows the general arrangement of the raw-mix hopper with feeder, elevator and nodule machine with sprays, feed hopper, travelling chain with casing, and the top end of the kiln, all in their correct relative positions ; the fan suction opening is also indicated in the side of the casing as well as the droppings-hopper with spiral conveyor at the bottom.

The nodule machine produces the nodules at the rate desired and delivers them on the feed chain. The conveying length of the feeder chain is about 25 ft. and its

width is about the same as the diameter of the kiln. The chain speed, which is adjustable, averages about 1 ft. per minute. The chain is close fitted (perforated trays) and the droppings amount to only about 5 per cent. of the total feed. The nodules are from ½ in. to 1½ in. in diameter and contain 12 per cent. to 14 per cent. of moisture. They are rolled sufficiently firm to ensure cohesion and to prevent them from falling seriously to pieces during transit to the kiln and during the early stages of decarbonating. The nodules are loaded on the chain to a depth of 6 in. to 8 in. The chain is enclosed in an airtight casing which it fits sideways ; the space above the upper part of the chain is in full communication with the kiln, and the space between the upper and lower part of the chain is in

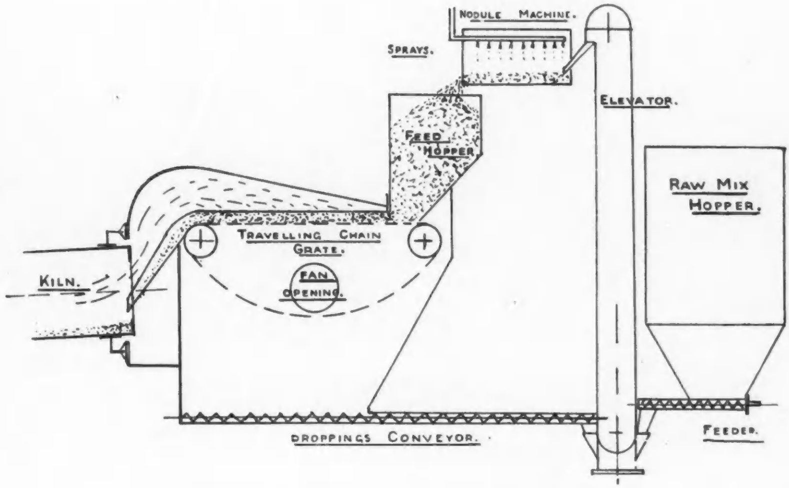

Fig. 4.—Sectional Arrangement of Lepol Kiln and Grate.

free communication with the fan to which it is connected by a duct of liberal proportions.

The gases from the kiln flow downwards between and through the nodules, which are in the gas stream for about twenty-five minutes, during which time the temperature of the gas falls from 1,200–1,100 deg. F. to 300–250 deg. F. The temperature of the upper layer of nodules is raised to about 1,100 deg. F. and that of the lower nodules to 300 deg. F. ; a fair mean figure for the temperature of the nodules would be 700–650 deg. F. A trace of moisture remains in the lower layer, but the decarbonating process has already well started in the upper layer by the time the nodules enter the kiln. The fan operates against a suction of 10 in., and the gases, which are steamy but free from dust, are discharged in the chimney stack.

The operation of the combination is good and results in a very low fuel consumption, but care has to be taken in the selection of the fuel as some impurities in the fuel, released during the combustion process, may be trapped in the nodule bed, which now acts as a filter, and returned to the kiln. The rated capacity of any kiln operated with a Lepol grate is increased considerably.

A test upon a Lepol kiln installed in Japan is given in full in *Concrete* (U.S.A.) for December, 1936 ; the fuel consumption for the kiln tested is stated to have been equal to between 13 per cent. and 14 per cent. of standard coal (12,600 B.T.U. per pound). Full data are given in connection with two other tests carried out on a Lepol equipment under different conditions in *Cement and Cement Manufacture* for April, 1932 ; these tests extended over a considerable period and the consumptions are stated to have been 13·54 per cent. and 14·36 per cent. of standard coal. The figures are given in full and are well worthy of study. Up to just before the war the makers (Continental) were prepared to supply these grates with a guaranteed fuel consumption of rather fully 14 per cent. of standard coal.

The Calcinator.—The calcinator is a bar-cage rotating cylinder arranged at the back end of the kiln so that it can deliver the treated slurry directly to the kiln. *Fig.* 5 is a diagrammatic section through the top end of a kiln with back-end chamber, feed chute, and calcinator in their relative positions, and the surface of the charge is also shown at its approximate working angle. The damper slide indicated at NN enables the kiln to be kept in service in the event of the calcinator being out of service, when a by-pass duct attached to the fan would be connected to the openings at MM.

The cage is of very heavy construction. Its internal diameter is 1·1 to 1·5 times the diameter of the kiln, its internal length is about 0·9 times its diameter, and its internal volume is about 10 per cent. of the volume of the kiln. It is charged with hollow circular cross, or equivalent, elements of about 3 in. bore, the gross volume of these elements being 40 per cent. to 45 per cent. of the internal volume of the cage. The speed of the cylinder is variable and adjustable from 0·5 to 1·5 revolutions per minute. The arrangement of the duct and the casing is such that all the gases must pass through the cage transversely to its diameter and through (or between) the elements with which the cage is charged. The slurry flows in intermittently under control through the space between those bars which momentarily are located near the top but on the rising side of the cage and splashes in and on and amongst the elements. A thin film of slurry adheres to the surfaces and in a short time becomes surface dried and falls off, later becoming noduled and falling into the kiln.

An extended article in *Cement and Cement Manufacture* for June, July and October, 1936, describes a complete test on a calcinator, and the data given indicate that the slurry probably remains in the calcinator for a total period of nearly three minutes. During the lesser part of this time the slurry is in film form adhering to the elements, but for the greater part of the time it is in a

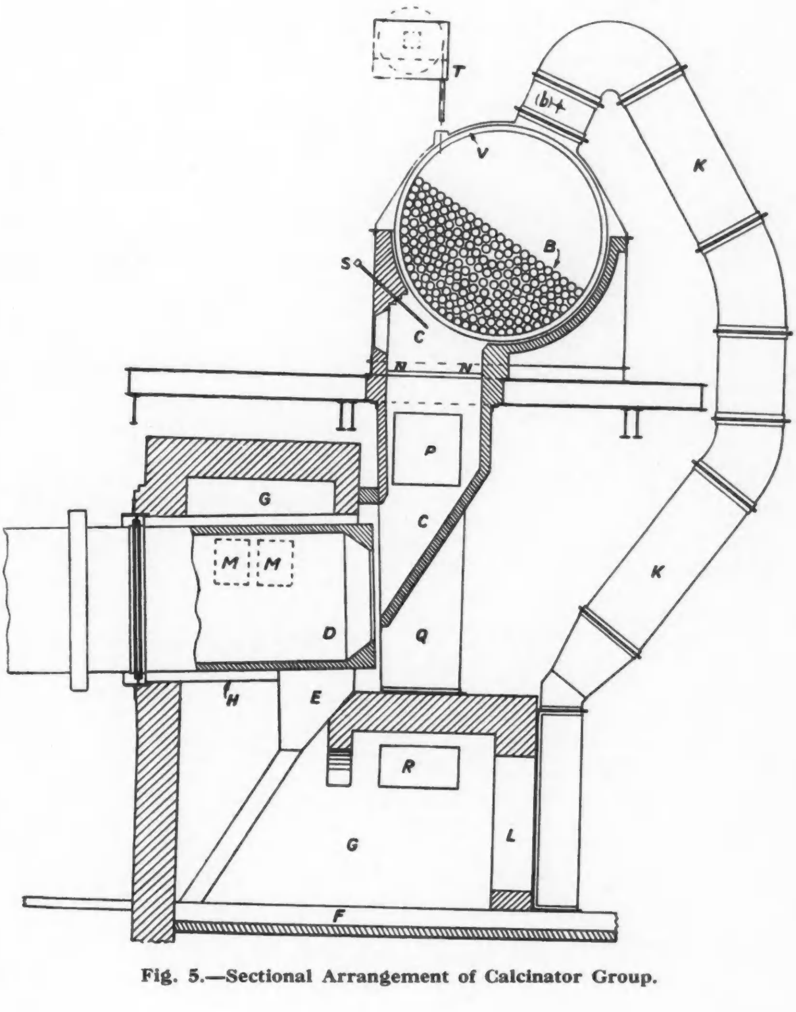

Fig. 5.—Sectional Arrangement of Calcinator Group.

" puggy " or nodule form being " noduled " up. During the latter period it is being dried and the temperature raised to 212 deg. F., for the temperature could not be appreciably higher than 212 deg. F. until the material has become quite dry. It need hardly be stated that a change of feed or speed of the calcinator will also change many of the operating conditions of the calcinator. The temperature of the gases as they pass through the calcinator and elements falls from 1,300–1,200 deg. F. to 275–250 deg. F. and, as stated, the temperature of the semi-dried slurry as it falls into the kiln is about 212 deg. F. The slurry nodules, or equal, are $\frac{1}{8}$ in. to $\frac{3}{4}$ in. in diameter, although some of them are already falling to pieces. The moisture in the slurry as it enters the calcinator usually varies between 39 per cent. and 43 per cent., and the moisture in the semi-dried slurry as it leaves the calcinator may average 14 per cent. The moisture content may vary between 4 per cent. and 18 per cent., and is largely dependent upon the rating, loading, and speed of the calcinator ; the form of the elements may also have some influence on the moisture content. The slurry in the 4 per cent. and 14 per cent. condition is in possible agreement with that in a chain-fitted kiln at positions of 25 per cent. and 33 per cent. of the kiln's length measured from the slurry end. The temperature of the barrel of any kiln that works in connection with a calcinator is very similar to that of a dry-process kiln, which in effect it is.

The use of the calcinator definitely reduces fuel consumption and the machine does not appear to require expert attention or supervision. The wear of the elements is serious and the cost of replacements considerable ; it should, however, be possible to reduce this by a revision of quantity, adjustment of speed, or change of material. The development of the machine is in its infancy and the design of some of the parts and fittings could probably be improved by close observation and adjustment. The amount of dust produced, owing to continued movement of the material during the drying process and to the action of the fan on the particles of dried slurry, is considerable and becomes a nuisance. Present experience with the calcinator indicates the necessity of initially installing a dust precipitator, or combination of cyclones or equivalent, to work in conjunction with the calcinator under any set of conditions ; it is again admitted, however, that more experience is required.

Clinker-Grate Cooler.—This, as its name implies, is a grate or grid that supports or contains the clinker during the period of cooling. In practice the grate is a double set of bars, each alternate bar being fixed or able to reciprocate under power movement. The grate is arranged at a sloping angle, or stepped, in the direction of motion. In addition to cooling, the grate invariably operates as a conveyor to transport the clinker from the kiln discharge to the transport system. The grate (or grid) is enclosed in an airtight casing or equal. A controlled quantity of air is blown into the casing and up through the clinker bed, and the passage of the air through the clinker effects cooling on the one hand and air heating on the other. The heated air, or some of it, is used as secondary air in the kiln. The clinker bed is or may be up to 10 in. to 12 in. deep.

These grates, which vary in detail and duty, are becoming popular in the

United States. They are usually arranged in two sections, the first operating as a " quencher " or rapid cooler and the second as a normal cooler ; water may or may not be used as part of the quenching procedure. Usually more air is used than can be taken advantage of in the combustion process and some or all of the low temperature (heated) air has to be wasted. The special duty or function of these grates appears to be that of quenching and rapid cooling rather than of air heating. Quenching and rapid cooling, as described, appear to improve some of the characteristics of some cements.

The operation of a special type of grate cooler and air heater was described in *Rock Products* (U.S.A.) for August 1939, and a letter in that journal for December 1939 refers to the same machine. This cooler was designed as a clinker quencher for initial rapid cooling. It is a two-section unit, the first section operating as a quencher and the second is for ordinary duty. The first section is 22 ft. long, and 9,000 cub. ft. of air per minute at 4-in. water gauge is passed through it. The temperature of the air after passing through the cooler is stated to be 970 deg. F., and it is passed directly to the kiln and used as secondary air for the kiln supply. The second section is 48 ft. long and 5,800 cub. ft. of air per minute at 2-in. water gauge is passed through it ; this air temperature becomes 345 deg. F. and it is passed into the stack and the heat wasted—filtration of this air is necessary. Although the figures given in the description are incomplete and lack precision, they indicate what is being done with units of this type. *Fig.* 6 shows a small-scale arrangement of a two-section cooler and also an enlargement of the grate unit ; this arrangement is not unlike that referred to in the text.

Comparison of Methods.

In reviewing these various auxiliaries it will have been noted that chain systems, the Lepol grate, and the calcinator deal with the conditions at the slurry end of the kiln, whereas the recuperator kiln (cooler) and the clinker-grate cooler deal with conditions at the clinker end. The former use the heat in the waste gases for drying and heating the slurry and also, as far as practicable within the limits of the heat available, for the decarbonating process. The other two extract the heat from the clinker during the cooling process and this heat, or some of it, is subsequently used in the combustion process. The heat reclaimed under both conditions is important but the latter is of much more value. The respective duties, however, differ considerably.

The highest possible temperature is necessary for the combustion process inside the kiln, and this high temperature is more easily attainable if air at high temperature is used for combustion. This also involves having the minimum quantity of excess air, and this combination alone will produce the greatest amount of high-grade heat. The greatest importance should be attached to obtaining good conditions at the clinker end of the kiln and the conditions at the slurry end should be kept subservient to the desired conditions at the clinker end.

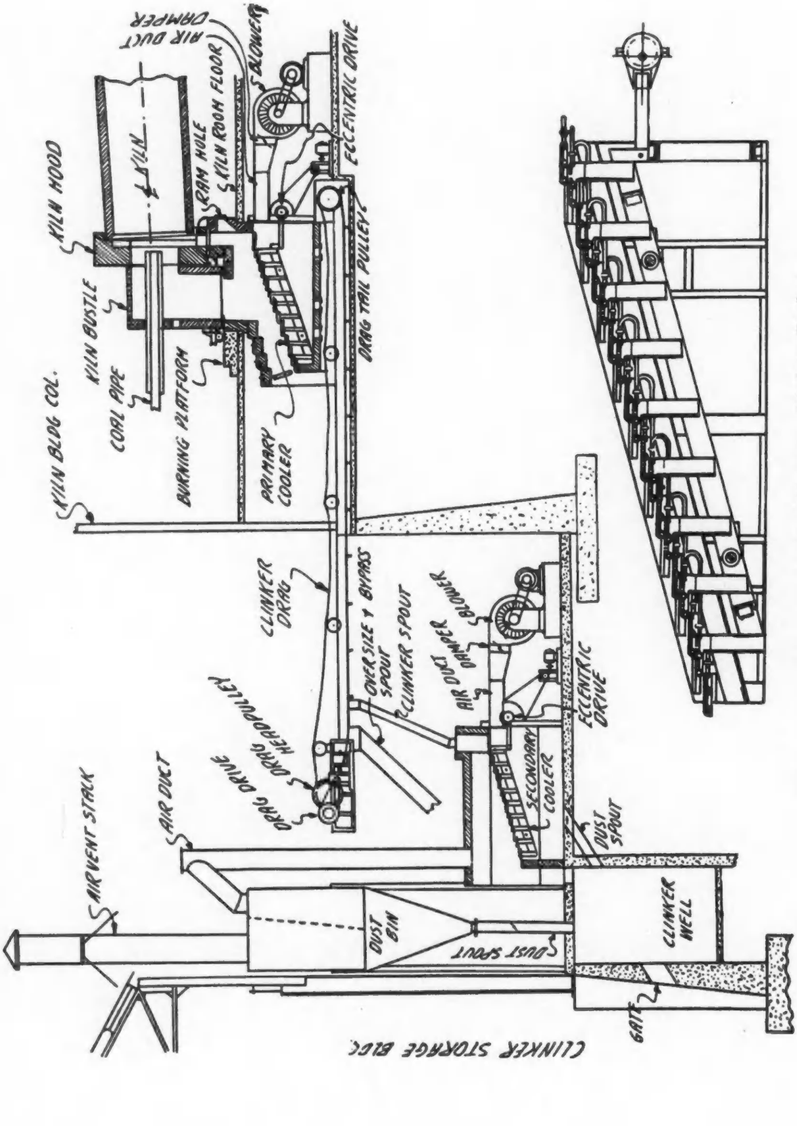

Fig. 6.—Arrangement of Two-Section Clinker Cooler.

As high-grade heat (1,480 deg. F. to 2,500 deg. F.) alone will produce Portland cement clinker of good quality, the fullest use should be made of any low-grade heat (below 1,480 deg. F.) to ensure that high-grade heat is not used for low-grade duty. Only a small quantity (say 5 per cent.) of excess air, for combustion, should be permitted at the lower end of the kiln, and the temperature of the whole of the combustion air should be raised as near as practicable to the combustion temperature of 2,500 deg. F. This should be done by using all the heat possible from the clinker in process of cooling, bearing in mind that any excess air or leakage air will lower this temperature and defeat the object in view. Having obtained the highest possible combustion temperature with high flame temperature, the work of final decarbonating and calcining will be carried

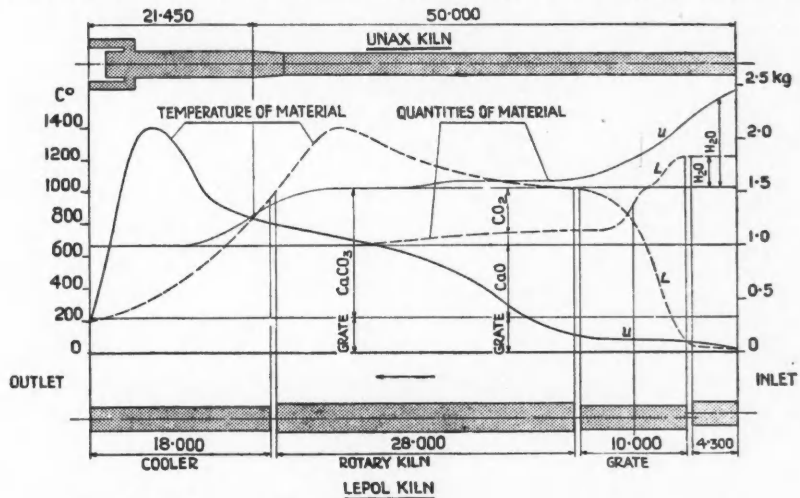

Fig. 7.—Diagram of Conditions in an Ordinary Kiln and a Lepol Kiln.

out positively and quickly; the early stage of decarbonating and the earlier preparatory stages will also be started upon on the material in process of coming down the kiln.

Leakage air at the slurry end of the kiln is not so important as that at the clinker end, as it in no way detracts from the heat or lowers the useful temperature; as it, however, gives the fan and the chimney stack more work to do, leakage should be prevented or eliminated at every possible point.

A careful consideration of the foregoing indicates why the principles adopted in the Lepol kiln (and grate) and the calcinator at the slurry end of the kiln, with well controlled combustion at the clinker end of the kiln, result in low fuel consumption. *Fig.* 7 taken from *Cement and Lime Manufacture* for May, 1939, shows the temperatures that obtain and the position where changes take place in the materials in a kiln that operates with a Lepol grate as compared with

those in a chain-fitted kiln ; the diagram indicates that the temperature of the material as it enters the Lepol kiln is not reached in the ordinary kiln until the material has passed along about 75 per cent. of the kiln's length.

It is very probable that the temperature condition in the Lepol kiln and the calcinator kiln is more or less comparable, although the decarbonating process has not made nearly so much progress in the calcinator kiln that it has in the Lepol kiln. From observation it appears that these two auxiliaries are not so sensitive to changes of moisture in the slurry and nodules, or to changes in the general operating conditions, as the chain systems. Each unit also enables a high gas temperature to be maintained throughout the length of the kiln, and this in turn results in better heat-soaking conditions for the decarbonating process. It further appears that the installation of either of these units enables the whole of the processes to be carried out in a reduced length of kiln, or, alternatively, it is possible to obtain an apparent increased rating of the kiln ; in fact, the installation of either unit would be equivalent to an increase of 20 per cent. or 25 per cent. in the length of the kiln ; we, however, have no information of the effect of such increase in length on fuel consumption.

Summary.

To summarise, chain systems are good and will conduce to lower fuel consumption if the raw material is suitable and the kiln can be worked at low rating. It, however, does not appear possible to obtain a fuel consumption lower than 23 per cent. to 24 per cent. of standard coal by means of chain systems alone, and even this figure, with most raw materials, will call for a low output rating and possibly also some special form of kiln.

The Lepol kiln and grate, apart from its limitations, is good and may be credited, at least so far as known, with the lowest fuel consumption on record and there appears but little risk of the dry slurry dust becoming a nuisance.

The calcinator is also good and it appears possible, assuming good combustion conditions, to work the kiln consistently with a fuel consumption of 21 per cent. to 22 per cent. ; even this figure may possibly be reduced if the operating conditions are of the best. The machine is of the simplest type and does not call for a specially high standard of maintenance and, so far as known, will work with all kinds of raw materials. Means, however, must be provided for dealing with the nuisance of dry slurry dust.

It may be stated that a fuel consumption of or about 22 per cent. provides but little reserve for waste, and it will therefore be necessary to keep all relevant parts in good condition and combustion well under control, otherwise it will be necessary to use extra fuel in order to make good the waste.

There appears to be no experience with slurry filters in Great Britain, but in view of the apparently promising experience with these units in the U.S.A. the opportunity might be taken of installing one and testing it, on limestone slurry for preference ; if fuel saving results, the experiments might prove worth while, for anything that promises a reduction in fuel consumption should have serious consideration.

Determining the Heat Evolution of Cement.

AT the twenty-fifth general meeting of the Association of Japanese Portland Cement Engineers, held recently in Tokyo, a paper on the determination of the heat evolution of cement was presented by Mr. Akira Takata, of the Research Office of Public Works of the Home Department of the Japanese Government.

The author said that the thermos-flask method of measuring the temperature rise in the heat evolution of cement, and consequently for calculating the amount of heat of hydration, is not a complicated procedure. Moreover, it has the

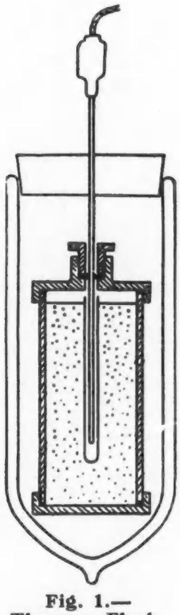

Fig. 1.—Thermos Flask.

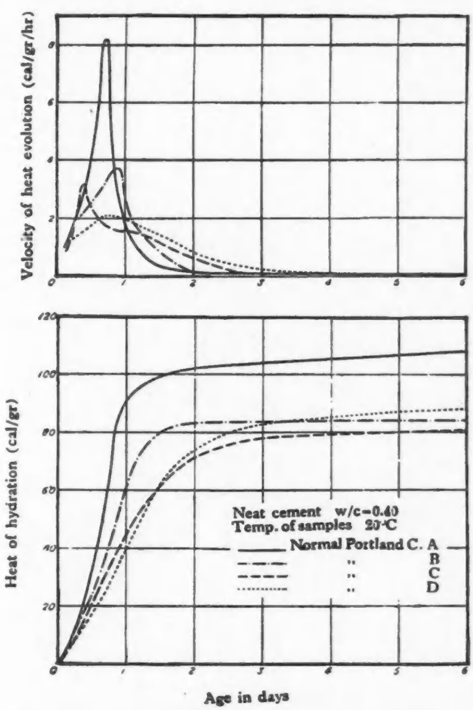

Fig. 2.—Tests on Neat Cements Cured at 20 deg. C.

advantage of bringing about several kinds of specimens simultaneously, having no connection with the type of cement or with the proportions employed in mixing the mortar to be tested. The procedure described is mainly in accordance with the method proposed by the International Commission on Large Dams, but that procedure is modified in the following two respects: (1) The thermos flask employed is that shown in *Fig.* 1. The flask is cylindrical in form, about 7·3 cm. in diameter and 22·5 cm. in depth; and its volumetric content is about 950 cc. The test specimen of cement paste or mortar is moulded in a brass container which has an upper diameter of 6 cm. and a base diameter of 5 cm. Its depth

is 14 cm. and its weight is about 930 g. This specimen within the container is inserted into the thermos-flask, an electric resistance thermometer being placed in the central portion of the specimen. The brass container is tightly fitted with a brass cover, so that no moisture can be dissipated from the specimen. (2) For the purpose of keeping the outside temperature constant an electric thermostat is used, in which a carbon lamp is placed as a source of heat. This is also fitted with an electric fan, and the temperature is controlled by a sensitive thermo-regulator and relay. Before taking test observations the entire apparatus, including the thermos-flask, the brass containers, the mixing tools, the cement, the quartz sand, and the mixing water, were all set in the thermostat for several hours so that all would have the same temperature.

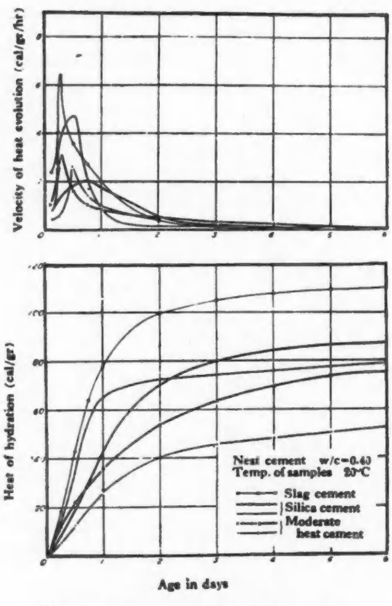

Fig. 3.—Tests on Neat Cements Cured at 20 deg. C.

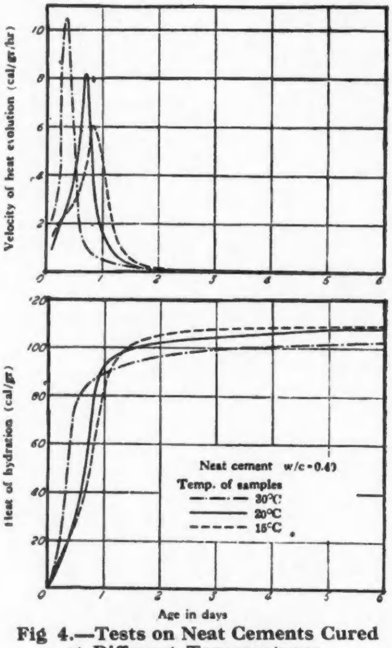

Fig 4.—Tests on Neat Cements Cured at Different Temperatures.

In this procedure the heat dissipated is calculated as the product of the leakage constant of the thermos flask, and the temperature curve of the specimen is plotted or recorded in a diagram as functions of time. The leakage constant of the thermos flask is obtained from the velocity of temperature decrease of hot water placed in the brass container within the flask.

Figs. 2 and 3 show the result of tests on neat cement mixed and cured at 20 deg. C. with a water-cement ratio of 0·40 by weight. Some differences are shown in these curves in the behaviour and the amount of heat evolution of the Portland, silica and slag cements, despite the fact that they are of the same general type. The velocity of heat evolution indicated in calories per gramme of

cement per hour increased rapidly from the start, attaining the maximum amount in a period ranging from five to twelve hours, then decreased fairly rapidly to a very small amount after two or three days. The velocity of heat evolution varies, apparently depending on the type of cement, the temperature of the materials before mixing, and the amount of water added.

An example of the effect of the temperature of materials before mixing is shown in *Fig.* 4. These curves show the results on tests of neat cement specimens for which the temperature of cement, sand, and mixing water were 30, 20 and 15 deg. C. respectively. These curves show that the velocity of heat evolution was greater with the higher temperatures, and the time required to reach the maximum velocity was shorter. However, the total amount of heat of hydration was less after several days than that of the specimens moulded at a low temperature.

The heat evolution of cement is also affected by the amount of mixing water in cases where the temperature is constant for all specimens. *Fig.* 5 shows the results of tests on neat Portland cement specimens mixed at 20 deg. C. with water-cement ratios at 0·40, 0·45 and 0·50 by weight. With the lower water-cement ratios the amount of heat evolution at the early stages is greater, while after several days the velocity of heat evolution is lower than the specimens having higher water-cement ratios. It was also found that in the specimens with the same water-cement ratio, those made of neat cement and those of cement-and-sand mortar do not necessarily give similar results in the matter of heat evolution.

In order to examine this point, some test specimens were made with a wet consistency and with cement and fine quartz mixed in the proportions of 1:1. It was found that the heat dissipated in the mortar specimens at the early stages was less than that of neat specimens, but after several days it was greater.

Inasmuch as concrete in large masses must be protected from fissuring due to expansion caused by internal heat evolution, it is imperative to use a cement with a low velocity of heat evolution. Furthermore, it is desirable to use a cement having a tensile strength greater than the ordinary. Cements having a high ratio between the tensile strength and the velocity of heat evolution are the more suitable for such massive concrete structures. According to observations on the temperature rise in dams under construction, the heat evolution in the concrete mass reaches its maximum velocity within seven days. This should be considered an important factor in conducting such tests.

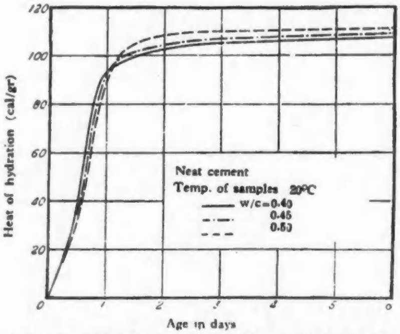

Fig. 5.—Tests on Neat Cements mixed with Different Proportions of Water.

By comparing the ratio between compressive strength and velocity of heat evolution among certain rapid-hardening and slow-hardening cements, little difference was shown in tests of mortar specimens mixed with a dry consistency. In specimens mixed with a wet consistency the tests show a higher ratio with the rapid-hardening cements than with the slow-hardening specimens. Silica cements and slag cements disclosed tendencies similar to those of Portland cement. In the ratio between modulus of rupture and velocity of heat evolution in the specimens mixed to a wet consistency, all types of cement produced similar results. However, there was considerable difference in the ratio between compressive strength and velocity of heat evolution. Similar tendencies were shown in the ratio between tensile strength and velocity of heat evolution in all specimens mixed to a dry consistency.